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A simulation-based decision support system The example of a furniture manufacturer

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Abstract: In this paper, we address a way to improve a classic kanban control system, by using kanban cards as an informational/decisional entity in order to enrich shop-floor information/decision. The real-time information collected and the simulation tool proposed enable to coordinate distributed decision according to a unique and global performance indicator. Our proposition consists in enabling any shop-floor decision maker to evaluate different kanban priority scenarios according to a unified objective, taking into account the global situation of the workshop. Models of the data collection and decision support system are presented. A generic information system enables to provide a relevant view of shop-floor status. Such information will be useful to efficiently feed a real-time simulation tool in order to evaluate solutions .The application is illustrated using the case of an industrial furniture manufacturer.

1. INTRODUCTION

This paper addresses a partnership between the TRACILOG team of CRAN[1] and one of the French first furniture manufacturers. The furniture production process of this company can be considered as sequential and its control is based on a kanban system. The need expressed by the client is launched as a work order, and then a card based system enables to spread priorities all along the production lines. However, such a control system does not specify every decision rules, and let place to operator local shop-floor decisions, for example when synchronising two kanban loops.

The supply chain manager evaluates production system performance according to a set of indicators, with a quite informal way. He looks at defining a relevant performance indicator qualifying the material output of the shop-floor. On the other hand, the main remaining drawback of this shop-floor control system is the lack of coordination between any local decisions : the global objective is not clearly formalised, and local decision makers do only have a partial view of the situation. Consequently, any production cell is controlled according to local objectives and information.

Recent researches highlight that holonic approach enables to coordinate any distributed decision using a holarchic structure and coordination mechanisms between software agents (Valckenaers *et al.*, 2006)(Chapurlat *et al.*, 2006). Such concepts are now well scientifically developed, and some works are done in order to study their scalability and their efficiency according to an industrial use (Cavalieri, 2003)(Mönch, 2006), specially the managing of emergence phenomenon. As addressed by Marik in (Marik, 2006), there is still a long way to make these heterarchical architectures efficient in real industrial environment. Among many issues to be solved, embedded devices as well as agent technologies are not yet sufficiently reliable and powerful to handle the scalability problems for fully distributing decision-making. Consequently, implementing a fully automated shop floor decision system will imply an important risk. However, proposed models could favorably be used to procure a decision-support to shop floor decision makers. In that sense, we will propose a structure enabling to provide an efficient shop floor decision support system, based on product identification and centered around the product. We also proposed the definition of a global indicator, which will enable to clarify and to unify the global objective of the production system.

The context of our work led us to have a particular application of the holonic concept, more particularly of the product driven system paradigm. Indeed, the basic decisional entity is the kanban card instead of the product. In this industrial application, each kanban card is able to carry information about itself and its associated products. Our proposal consists in enabling any shop-floor decision maker to evaluate several possible solutions according to a unified objective, and taking into account the global situation of the workshop. Such a tool relies on two main elements: a clearly identified performance indicator, which could be parameterised by the management, and a decision support system which enables any decision-maker to globally evaluate the impact of several solutions. In this paper, we define the unique global indicator, and we propose an architecture enabling real-time data collection and solution evaluations thanks to a simulation tool. This considerably simplifies the architecture, and simulation studies shown the relevance of such a solution according to global performance. The structure has been built to support evolutions if future works allow considering the implementation of a fully automated distributed decision system.

First, we will detail what kind of flow management decision are taken on the shop floor, and how to quantify their impact in order to select the better one according to performance

[1] www.uhp-nancy;fr

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objectives. Secondly, we will highlight the benefits of having a global view of the shop floor status and the product sensing skills to provide such information (Mac Farlane *et al*, 2003). Then, we will present a structure enabling data collection and computing in order to support shop floor decision making processes by evaluating solutions before to conclude on future developments.

2. PROBLEM STATEMENT

2.1 Production process

First, the company sales ready-to-assemble furniture's. Function of the number and the size of different parts, one furniture reference can be delivered as one or more packages. Each package contains manufactured parts and bought components. The product model is described on figure 1.

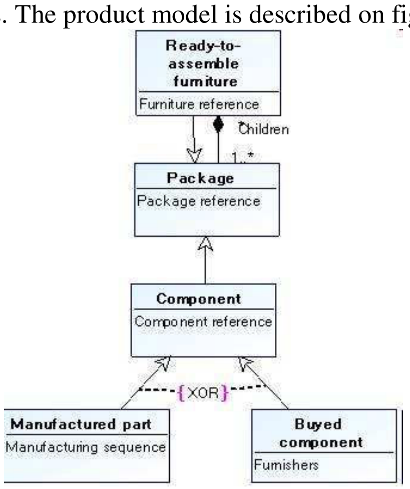

Figure 1. Product model (UML Class Diagram)

The considered company is composed of three autonomous production units, each one being able to independently manufacture furniture's. We will particularly focus on one of these units, producing the middle of the product range.

The studied workshop produces sizeable volume of many different products (about 2000 finished goods references, more than 10.000 manufactured parts references and about as many bought components references). A decoupling point has been created to face management problems, and the production control is different before or after this point:

- Before the decoupling point, the bottleneck Cut-to-Size machine is a batch process, and the raw material optimization constraints implies significant volumes,
- After the decoupling point, the workshop transformation process is managed by orders, using a classical final assembly schedule.

The studied system is a panel board, ready-to-assemble furniture production system. Furniture's manufacturing relies on a composition of three main functions: first, large panels are cut into pieces; secondly, pieces receive some transformations, like drilling or grooving, and then finished pieces are assembled into a package, which will be brought to the final customer through the distribution system.

First, particle panels have to be cut to size. The cut to size tool is quite hard to manage because of the specificity of the process. This is not in the scope of this work. A dedicated simulation tool has been developed to improve the management of this facility (Klein et al, 2006), and its output is used as technical data. the raw material being one of the mains costs (more than 50 % of the cost price), and scrap rate decreasing when lot size increases, the lot size have to be at least 200 and optimal lot size according to logistical and material constraints have been estimated to be about 400.

After this cutting process, pieces are manufactured to become finished parts. The workshop is constituted of several machines, each one being able to perform some operations. The variety of different parts, the significant volume produced and the important number of lots being processed simultaneously lead to an important physical flow complexity, which makes their control difficult. Then, when any components for a package are available, the assembly is launched on the packaging line with corresponding hardware. The beginning of the production process (cutting operation) is released by packaging line activity. Consequently, the different lots are pushed through the shop floor thanks to kanban cards. A synoptic of the production process is shown on figure 2 (Processes have been modelled using the MEGA Business Process modelling suite[2]).

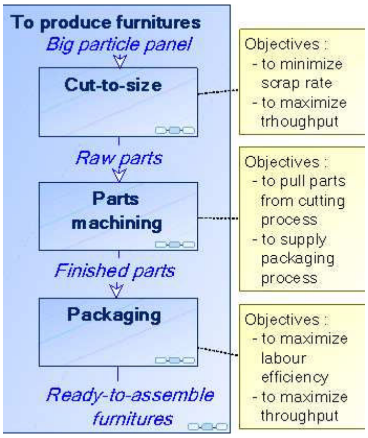

Figure 2. Furniture's production process

The inherent characteristics of each process lead to work with items belonging to different levels of the bill-of-material.

- in order to maximize cutting run volumes, the cut-to-size process deals with whole furniture's : any parts of a finished products are cut during the same operation,
- Due to the specificity of each part, machining processes deals with the part level,
- Then, obviously, packaging process deals with the package level.

In order to cope with these different management modes, decoupling points have been created between production cells. The management of such decoupling point has been

[2] www.mega.com

identified as a key of success. The lack of a detailed visibility of the content of the decoupling inventory led to manage it according to Work In Process (WIP) level, because a full inventory disturb the flow, and a near empty inventory often results in costly resources starving. The control of such a decoupling point faces two problems, which are to bring the WIP between two predefined critical threshold and to control lead times.

2.2 Production process control

As addressed in the previous section, the product volume and weight, as than process complexity make flows hard to control. A physical scheduling system, based on kanban system, enables to control the production system (Figure 3). Fixed size orders are released according to client consumption. Priority are forwarded by package reference all along the manufacturing process : that is to say any pieces belonging to the same package will be successively processed on each cell. Such a scheduling process does not take into account the variety of lead-time due do different part complexity. For example, when machining a wardrobe, parts like shelves will be finished after cutting, when doors could need four operations as drilling or pasting a mirror.
The product-mix variability as than process WIP inventory in front of the packaging line is overloaded by short-sequence parts of different packages, but not any package could be assembled due to the lack of one or more long-sequence part. In order to avoid such a situation, shop-floor decision maker sometimes dynamically adjust the detailed scheduling in order to speed up a part or to speed down another one.

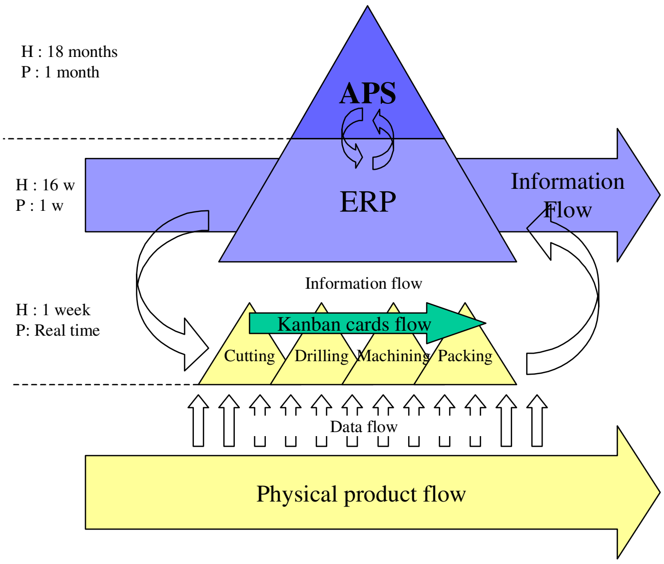

Figure 3. Kanban production control system

2.3 Performance evaluation

The shop-floor manager evaluates performance according to several objectives. The dashboard relies on a set of indicators:

- Output : number of produced package items,
- Total tardiness : number of late items,
- Finished goods inventory level,
- Bottleneck use-rate,
- WIP level.

This set of indicators enables to properly describe the production process performance, but there is a lack of a synthetic indicator. Indeed, the global production manager assigns an informal objective. This leads each shop-floor decision maker to interpret the objectives when taking a decision according to several criterions.

In order to improve performances and to involve operators, a decentralized organisation have been established. Then, any operator is able to manage its resource according to its objectives and to its perception of shop floor status and order priorities. Due to the important surface of the workshop, resources operators only have visibility on what is just in front of their resource. Moreover, shop-floor decision makers could not have a predictive view on what is going to happen. Similarly, commercial priorities and their changes are only passed through oral communication. This results in a decision making process based on a partial view of the situation, according to local objectives, and without an evaluation of the global impact of adopted solution.
Giving to the shop floor decision maker an information system in order to broadcast global objectives and constraints and to provide a detailed view of production progress have been identified as being an efficient way to improve global performances But the heterogeneity and the complexity of existing information system induce an expensive integration task. Moreover, when installed fifteen years ago, information system was not built to meet real-time access requirement. Feeding it with a important mass of data, and increasing the amount of simultaneous access could quickly lead to an informatics breakdown. Such a context implies to deploy an architecture meeting real-time constraints and enabling multiple simultaneous access, then we turned toward a three tier architecture using web technologies.

3. PRODUCT SENSING AND SHOP FLOOR VISIBILITY

In section 2, we underlined the need for shop-floor visibility but the expensiveness of developing a support to it. On the other hand, we postulate that centering the information system on the product simplifies integration and reduces synchronization problems
Many research efforts have been done to develop and to formalize new approaches in order to improve production systems reactivity and agility (Morel et al., 2003), (Valckenaers, 2006). The product driven paradigm suggests considering active the infotronic product as the link between physical production system and the business functions. Control system models have been built and some experimental are done, using simulation and lab test-bed. But the scalability of such systems is not enough proven, and the management of a well-sized emergent system seems not to be ready to face industrial constraints as the need of robustness or real-time running. However, it seems profitable to enrich shop floor decisions making processing using product information to ensure global coherence and optimisation.
Kanban scheduling system is an efficient tool to broadcast information on the shopfloor, and then to drive flows, but there is a few bottom-up information flows which makes

difficult to take into account global optimisation when taking a decision. In order to provide a way to maintain and to broadcast a relevant perception of the situation, which could be assumed as holonification, we propose a Manufacturing Execution System fed by data from resources and infotronic kanban cards (figure 4).

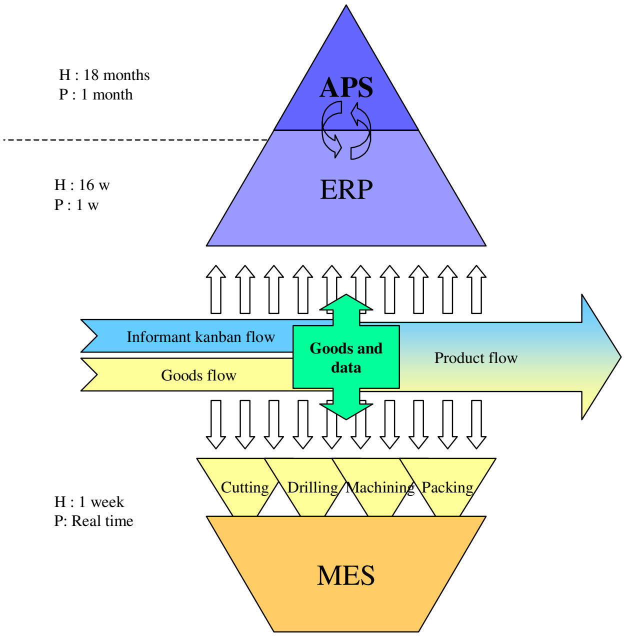

Figure 4. Product driven system

The proposed MES does not fully meet the eleven core functions summarized by the manufacturing execution system association[3] because some of them are already implemented, but an extension of existing functionalities could easily be considered. The presented structure now implements data collection, process management, product tracking and performance analysis functions, and a decision support to resource allocation, detailed scheduling and dispatching.
To be efficient, the existing information system need to be continuously fed with data about shop-floor status evolution but it does not meet real-time requirements. In order to cope with real-time and scalability constraints we deployed an independent structure collecting data about process events and then consolidating them. This structure has been developed using well tried web technologies. Then, to assist shop-floor decision makers to evaluate the global relevance of their decisions, a simulation tool has been linked with this database.

4. A DECISION SUPPORT SYSTEM ARCHITECTURE TO IMPROVE PRODUCT FLOW CONTROL

First, we could identify the functions we intend the system to provide, according to the needs expressed in previous sections :

- Product and shop floor events sensing : the system have to collect any event occurring on the shop floor, in order to maintain a relevant view of the shop floor status,
- Maintaining a consistent view of shop floor status: using a consistent re-usable database.
- Events filtering and database updating : a module of data computing select relevant shop floor events, and manage the database update process in order to maintain it conform with the physical world state,
- Providing relevant information to decision makers : a user-friendly interface enables to provide synthetics views of resources or orders status,
- Evaluating available solutions : a coupled simulation tool enable to quantify and to compare available solutions with regards to global performance.

The global structure is shown on figure 5.

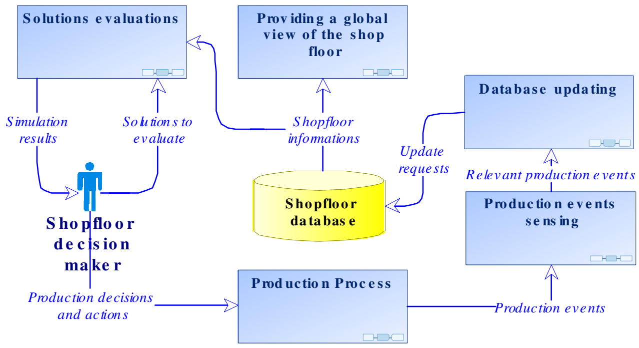

Figure 5. Decision-making System architecture

First, and before to enrich shop-floor level information in order to improve visibility, we have to clearly define and formalise the global objective. Each decision center is able to evaluate its impact on global performance using a coordinating decision support system.

4.1 Maintaining a consistent view of shop-floor status

This function could be brought down into two sub-functions, which are storing information and providing a synthetic access to shop-floor information. To cope with company policy and with our needs, we used a three-tier internet oriented architecture.

In order to be generic and re-usable, we broke down the database into three subsystems (see figure 6). IEC/ISO 62264 standard was not fully implemented because any functions where not needed.

- A technical data subsystem, organized following the using B2MML[4] specifications, based on sequence description using product and process segments.
- A dynamic data subsystem, containing an object for each object of the emulation model maintaining a consistent image of the shop-floor status, used to initialize simulation and then to follow it,
- A tracing subsystem enables to trace any events about products and resources.

[3] www.mesa.org

[4] www.wbf.org

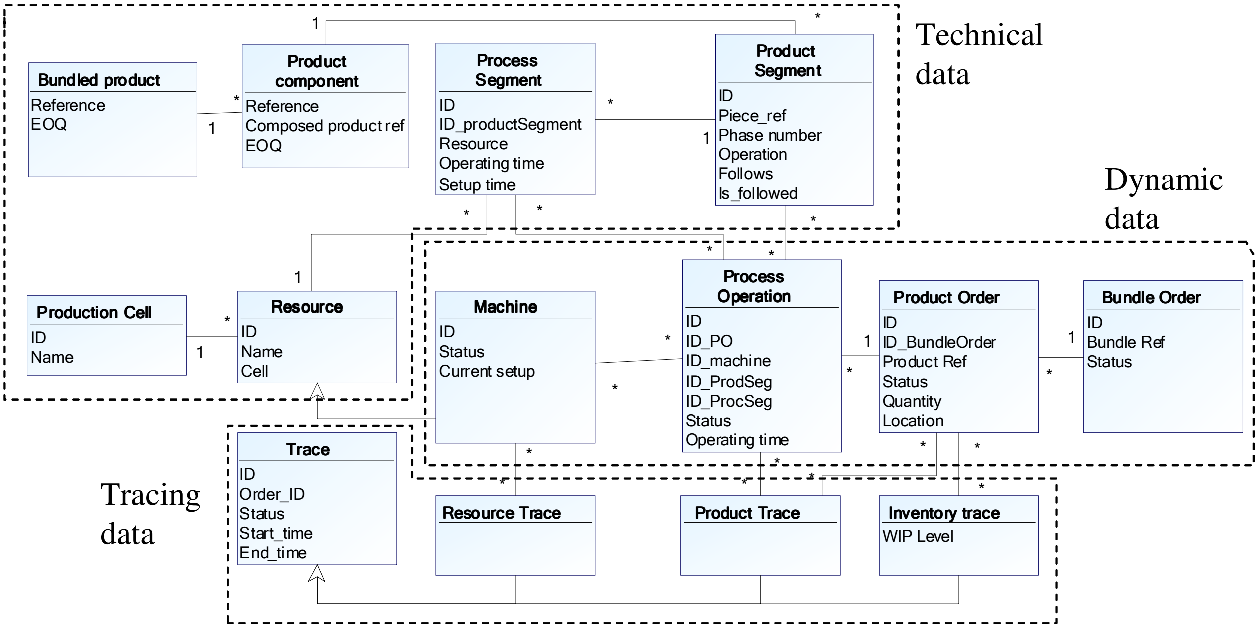

Figure 6. Information System relational Model

4.2 Events filtering and database updating

The event filtering module is in charge of converting data about shop floor event into relevant update requests. For example, the event noticing the end of an operation O involving Product Order P on the Machine M will generate following requests :

- Ending the operation O, by updating its status to "Ended", and filling the "End time" field,
- Updating the following operation O+1 status as "Available",
- Updating the Product order P status to "Finished", if the operation was the last one of manufacturing sequence,
- Assigning the machine M the next operation to process, or updating its status to "Idle",
- Recording if necessary the operation traces as product trace, resource trace or inventory trace.

4.3 Providing relevant information to decision makers

The previously presented database enables to maintain a detailed consistent view of the shop-floor, at real-time. Then, information have to be fitted, in order to provide synthetic and relevant information to each decision maker, through a user friendly interface. In that sense, interviews enabled to identify needed information on each decision point, and then views have been developed using web technologies. This enable a simplified upgrade in order to fit with users needs changes. For example, an information about the finished parts (components) inventory level, in front of the packaging line; will enable machining resource operators to anticipate on a possible starving by swapping two orders.
If such a system clearly improve the local quality of taken decision, it does not enable to ensure any taken decisions will be profitable according to the global objective.

4.4 Evaluating available solutions

The amount of information provided and the complexity of the global optimisation problem imply a need to assist decision makers. Moreover, the availability of consistent data enable to efficiently feed a simulation tool in order to evaluate some of the possible solutions. A simulation test bed had already been developed and presented in (Klein et al, 2006), which enables to offline evaluate several solutions according to WIP level and productivity criterions. The simulation model has been validated using several test cases, and results about WIP level or lead time are considered as realistic (less than 5% gap). This architecture have been adapted to online-use requirements. The simulation architecture to evaluate is shown on figure 7.

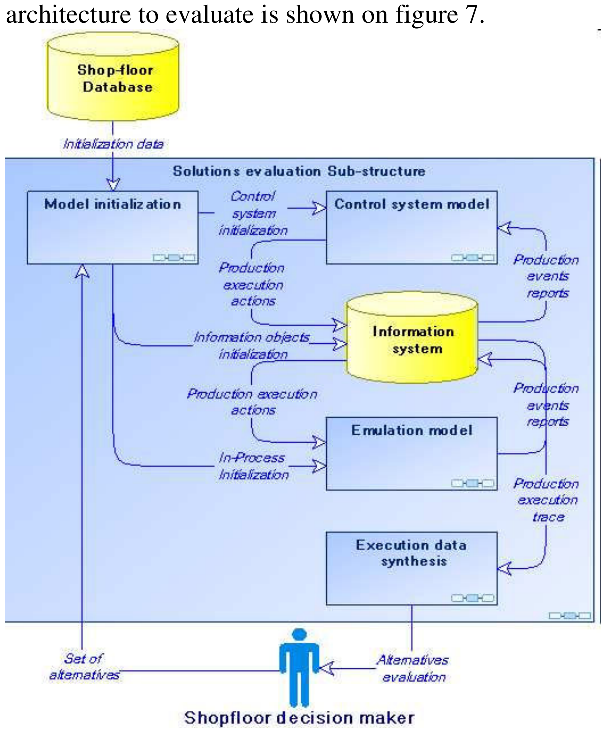

Figure 7. Architecture to evaluate

The first and fundamental operation to achieve in such a simulation use is the model initialization. The used simulation architecture is based on a distinction between process emulation and control system, and a database enabling to synchronize both executions. The database structure enabling this interface is structured exactly like the informational system shown on figure 6.

The main drawback of the presented simulation tool was the lack of clearly identified global objectives. The better solution was different function of the point of view of the decision-maker. Consequently, study led to identify the global objectives and to establish a relevant indicator, allowing any shop floor decision-maker to quantify the global impact of their decisions.

According to (Mönch, 2006), we established the performance tree in order to quantify the global performance of the production system. The main objective could be synthesized as Producing what the client need, when he need, in the quantity needed, at the best cost. This could be quantified as Client Satisfaction (CS) and Productivity (P). CS is broken down into two quantifiable indicators : Total Tardiness (TT) which reflects number of late orders weighted with order quantity, an Demand Respect (DR), which reflects the proportion of on-time orders for each week. P is characterized as a function of raw-material scrap rate (SCR), and as Output (O) which quantify the output. These four basic and quantifiable indicators enable us to synthesize the global production system performance as (PP).

$$\text{Client Satisfaction} \begin{cases} TT = \dfrac{\Sigma(\text{quantity of late orders})}{\Sigma(\text{quantity of any orders})} \\[2ex] DR = \dfrac{\text{Number of order produced on time}}{\text{Number of order to produce}} \end{cases}$$

$$\text{Productivity} \begin{cases} SCR = \dfrac{\text{Volume of packaged parts}}{\text{Volume of consumed panem}} \\[2ex] O = \dfrac{\text{Number of produced packages}}{\text{Nominal output}} \end{cases}$$

$$\boxed{PP = a.TT + b.DR + c.SCR + d.O}$$

a, b, c and d coefficients are fixed by the management according to the production system objective. Then, shop-floor decision makers evaluate any local decision according to the unified objective which is to maximize PP. The simulation architecture, coupled with a test case library, enables to empirically optimize the set of parameters, using the manager knowledge. They are able to simply define and evaluate several schedules for their machine and retain the better solution comparing their impact on global production system performance, using a user friendly interface.

4.5 Implementation and results

According to our needs and to company specifications, the implemented structure relies on a MySQL database and PHP web pages.The database has currently developed and its consistency is now shown. It is connected with production event sensing module and provide at real-time a detailed view of the production system status. The solution evaluation module is fed using this information and provides a realistic evaluation of different solution. A real condition test showed an improvement of the global productivity by reducing packaging line starvation, thanks to a better synchronization between machining centers. This results in an improvement of 2% of the packaging line use rate, and then, in an equivalent improvement of global throughput. The deployment is now ready to be done, but the expensiveness of discrete-event simulation software licenses make it really costly. Solutions like centralised simulation executions or the development of a simple discrete-event simulator are studied.

6. CONCLUSIONS

In this paper, we addressed an interpretation we done of currently proposed production control systems like product driven systems, adapted to the constraints fixed according to our industrial partner. Consequently, we developed a way to improve a classic kanban control system, by using kanban cards as an informational/decisional entity in order to enrich shop-floor information/decision. The technical structure model is presented and validated, and the construction of the global indicator giving cohesion is detailed.

Future development will be to deploy the decision-support tool on the shop-floor, and then two translate it on two others similar production cells. Improvement could be done on the solutions construction process, by studying the ability to constructs several solutions using a emergent cooperative structure.

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